View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Research Papers in Economics

Case Study of On-Farm Experiments and Farm Management Decision Making

Terry Griffin
Assistant Professor and Extension Economist
University of Arkansas Cooperative Extension Service
2301 S University Ave
Little Rock, AR 72204
501.671.2182
501.671.2297 (FAX)
tgriffin@uaex.edu

Craig Dobbins
Professor and Extension Economist
Department of Agricultural Economics
Purdue University

Jess Lowenberg-DeBoer
Professor and Extension Economist
Department of Agricultural Economics
Associate Dean
International Programs in Agriculture
Purdue University

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland, OR, July 29-August 1, 2007

Copyright © 2007 by Terry W. Griffin, Craig Dobbins, and Jess Lowenberg-DeBoer. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Introduction

A three-year case study was done to better understand farmers' use of on-farm trials and how localized on-farm data influences their decision making process. Case studies were chosen to evaluate the behavior, perceptions, and opinions of farmers because 1) surveys would have very small sample size, 2) the research investigators already were working very closely with the case study subjects, and 3) lack of general background information on the research topic. Case study methodology provides in-depth information suitable to apply local information to the general theory answering "how" and "why" questions (Yin, 2003).

In particular, case studies focused on two groups by which the farmer-subjects were categorized. The groups were based upon whether the farmer received a spatial analysis report of their on-farm trials and were only used to test the intervention by this project via the spatial analysis service and associated report. Case study farmers from both groups were expected to provide insight on the entire gamut of precision agriculture and on-farm trials with the exception of the intervention due to this research. Both groups assisted this research by conducting field-scale experiments to ascertain ease of experiment implementation, appropriate data collection, and data handling procedures.

The first group includes farmer-collaborators who received spatial analysis reports and are referred to as the reference group (see Appendix) for sample spatial analysis report regarding on-farm trials presented to farmer-collaborators). The second group referred to as the comparison group includes farmers experienced with conducting on-farm trials but who did not receive spatial analysis reports prior to the interview. The United States Department of Agriculture – Sustainable Agriculture Research and Education (USDA-SARE) Graduate Student Grant Program funded this participatory on-farm research.

Farmers in general as well as collaborators with this research comment on difficulty of conducting on-farm trials. On-farm research logistical problems arise from difficulty in implementation of experimental design, communication between farmer and analyst about the design and data, difficulty in data assimilation, and complexity of data analysis interpretation. In addition to these experimental design obstacles, this case study examined spatial analysis services, and farmers' confidence in data, field-scale experiments, and farm management decisions.

Case Study Background

This case study research built upon earlier work related to adoption and use of yield monitors (Daberkow and Fernandez-Cornejo, 2006; Fountas et al., 2005; Urcola, 2003). Case study techniques have been used in agriculture for farm management topics (Doye et al., 2000; Malcolm, 2004), agribusiness (Harling and Akridge, 1998; Harling and Misser, 1998; Antle and Pingali, 1994; Boland et al., 1999; Dorward et al. 2003; Westgren and Zering, 1998), and for precision agricultural issues (Grisso et al., 2002; Popp et al., 2002; Urcola, 2003). Doye et al. (2000) and Urcola (2003) are the most pertinent examples of prior case study research relevant to this case study research. Doye et al. (2000) interviewed five farms over a two year period and presented in-depth farm-level information and a final comparison among farms.

Urcola (2003) used case study methods to understand cultivar selection practices of ten Indiana farmers in their decision making processes. Urcola's (2003) case study subjects were segregated into two groups: those with GPS yield monitors and those without the yield monitor. Case study methodology rather than a formal survey instrument was used due to the dearth of information on yield monitor use in seed selection decisions and the limited number of farmers experienced with yield monitor use at the time.

Urcola stated that farmers evaluate genetic performance in their local environment with yield monitors even though yield map interpretation continues to be considered difficult (2003). Fountas et al. (2005) reiterated the point by reporting 22% of U.S. farmers in his sample stated yield map interpretation was difficult and 69% of farmers felt data handling took too much time.

Urcola's results suggest that farmers with yield monitors are decreasing the use of strip-trial designs in favor of large-block split-field experimental designs. Urcola also suggests that farmers with yield monitors place more weight on on-farm trials than farmers without yield monitors which was reaffirmed by Daberkow and Fernandez-Cornejo (2006) who reported that on-farm trial data collection was the third highest use of yield monitors from the USDA-ARMS survey with 43% of respondents with a GPS unit used the technology for on-farm trials.

Hypotheses and Methods

Hypotheses were chosen based upon a review of the literature, prior information, and experience working with farmers. Hypotheses are:

- H1 farmers use a combination of sources of qualitative information in making decisions: experience, crop consultants, university Extension, dealerships, and other farmers,
- H2 farmers use quantitative information from off-farm yield trials such as university, industry, and farmer association research,
- H3 farmers have more confidence in their on-farm trial based farm management decisions analyzed with spatial analysis than with traditional non-spatial methods,

- H4 farmers value yield monitor data on their own farms because it shows localized yield response under their local environmental conditions,
- H5 farmers who use yield monitors have dropped the use of other methods used to measure yield (i.e. weigh wagons, scales, scale tickets),
- H6 GPS-enabled navigation technologies impact on-farm trials,
- H7 analysis of hybrid and variety trials must be completed and received prior to end of current year,
- H8 the timeliness of analysis results are as important as content of analysis results, H9 printed yield maps have limited value,
- H10 farmers prefer to make on-farm comparisons in large blocks such as split-field designs rather than strip-trial designs,
- H11 farmer relationships with university Extension were strengthened from involvement in this project, and
- H12 farm managers are more willing to conduct and participate in regional on-farm research projects than before this spatial analysis project.

These hypotheses were evaluated using the case study methods suggested by Yin (2003), in particular the general strategies for case study analysis of theoretical propositions and rival explanations using cross-case synthesis as the specific analytic technique (Yin, 2003). Cross-case analysis uses non-numeric interpretation to compare individual cases of a multiple case study.

The reference group interacted frequently with researchers. The comparison group interacted with researchers to a lesser extent. The influence of intervention was evaluated by comparing the reference group with the comparison group. Cross-case syntheses include an intervention, e.g. participation in and receiving a spatial analysis report from, with a comparison, e.g. non- reference group.

Case Study Data and Analysis

Five farmers from Indiana, Illinois, Kentucky, and Ontario were interviewed using case study methods presented by Yin (2003) to evaluate each farmer-collaborator as a unit of analysis. Three general information gathering techniques included direct observation of farmer, participant-observation of farmers during the project, and open-ended interviews, with the latter as the primary source of data. Researchers made multiple farm visits, analyzed on-farm trial data, and provided farmers with spatial analysis reports. Semi-structured personal interviews loosely followed an interview script allowing respondents to comment on specific questions while providing the opportunity to openly remark on their experiences. Farmers were observed and interviewed concerning unbiased local production recommendation information from spatial analysis, experimental designs, and their farm management decision making process.

After interviews were completed, information from interviews was summarized into seven topics including: 1) uses of yield monitors, 2) GPS-enabled navigation technology effect on on-farm trials, 3) spatial analysis services, 4) decision support systems, 5) experimental designs, 6) advice for farmers conducting on-farm trials, 7) and role of university Extension. Case study evidence was distributed to farmers for review.

Case study farmers were initially identified as innovators because of their stated interest in on-farm trials with yield monitor data. Thus, case study subjects differed from representative U.S. farms because they performed on-farm trials and sought statistical analysis techniques. Basic information for all farmers include general geographic location, the farmers’ research questions, experience with on-farm trials and precision agriculture, and crops grown. Specific information alludes to uniqueness of each farmer.

Besides having extensive experience with yield mapping and conducting on-farm trials, all subjects were well educated with at least a B.S. degree and maintained strong relationships with their respective Land Grant universities, attesting to their analytical disposition and commitment to life-long learning. Farm operations were geographically dispersed from one another across four U.S. states and Canada.

All subjects were at least second generation farmers although some developed their operations independently of the preceding generation. Although some case study farmers once had livestock, none do at present. All farms have computer email. Another commonality among subjects was that short-run profitability was not the only farm management goal. Environmental stewardship existed in the form of not trading short-term gain for long-term expense when it came to their land.

Reference Case Study Group

The three reference group farmers compose the first case study group. The field-scale on-farm trial studies and spatial analysis reports for each of the reference group farmers are described in Griffin (2006). The spatial analysis report was accompanied by a cover letter stating the summary of the report and a CD with electronic files of the report and a partial budget spreadsheet if the farmers wanted to conduct their own sensitivity analysis.

Farmer D

Farmer D is a sole-proprietorship irrigated producer in Tazewell County, Illinois. Soils range from high organic mucks to sands, often within the same field. Topography influences both yields and yield response to input. Due to being a minor soil formation area of the state, limited public research has been conducted that directly impacts production in this isolated region. Crops grown include corn, soybean, popcorn, green beans, and seed corn. The Illinois Farm Business Farm Management Association (FBFM) tracks financial information. Farmer D is a graduate of Illinois State University. Farmer D has collaborated with this research since the inception of the project and wrote a letter of support for the original SARE grant application.

Manual lightbar navigation has been used for four years; however, no automated guidance has been used. Variable rates of lime, phosphorus, and potassium have been made over the past five years. Farmer D has been using computers and internet for 10 years. Their first yield monitor was bought off the back of a flatbed trailer at an auction in 2000 and they began collecting georeferenced yield data and using farm mapping software the following year. Farm level mapping software has included SMS Advanced with GeoDa (Anselin, 2003) being instated as a direct result of this project. Farmer D was noted as saying "The more technology used, the more useful it becomes."

On-farm trials have been conducted to gain useful local information for more than 20 years. Previous on-farm trials included corn hybrids, corn fungicide and insecticide seed treatments, plant health soybean fungicide, fertility rates, and soybean and popcorn seeding rates. Future experiments will focus on hybrid by soils and fertility experiments. Farmer D stated that the larger time requirements from some experimental designs increase chances of error; however he is concerned with the reliability and reproducibility of results. Farmer D stated the importance of "designing experiments rather than answers."

Farmer D stated that spatial analysis of on-farm trials allowed him to make decisions differently. Specifically, he had more confidence in making the decision and in the decision itself. In addition, decisions were made faster and more decisions were made that would not have been made otherwise. Making decisions quicker impacts costs of production and level of production by selecting appropriate hybrids and placing orders in time to secure early discounts.

Similar to marketing clubs that Extension has facilitated in the past, “yield monitor data analysis” clubs would be a role for Extension. Farmer D stated that interacting with other farmers conducting similar research due to this project was “encouraging because he was assembled together with other farmers having similar goals and problems” and reinforced that “local neighbors were not the only other type of farmers.”

Farmer F

Farmer F is in Montgomery County, Indiana and has been involved in the SARE project since inception. Crops include corn and soybean in rotation. Fields are rolling hills and some eroded hilltops have resulted from previous conventional tillage practices. All farms have been converted to strip-till production over the past five years. Farmer F is a graduate of Purdue University.

Farmer F has been using computers for more than 12 years and internet nearly 10 years. Manual lightbar navigation has been used for four years prior to adopting automated guidance four years ago. The highest level of GPS accuracy, RTK-GPS, has been used for automated guidance the last three years and is currently used on four tractors. Yield mapping and farm mapping software have been used for seven years with AgLeader SMS software currently used. Variable rate applications of lime, phosphorus, and potassium have been used for four years.

On-farm trials have been used for the past 11 years. Elevation and soils are expected to influence yield and yield response to input use. The RTK-GPS signal is also used to collect dense elevation data for digital elevation models for use in spatial data analysis. Future on-farm trials include nitrogen application timing on corn including split applications, deep placement of phosphorus and potassium fertilizer, and foliar fungicide and insecticide treatments. Rather than printing yield maps, subjective and objective analysis can be performed electronically "if the computer monitor screen is big enough." In addition, all rented farmland is on a cash rent basis rather than crop shares so landowners have less interest in printed yield maps.

Farmer F stated that for either private or public sector, personal relationships and trust are important with respect to making decisions with assistance from advisors. The spatial analysis report contained the farm management recommendation on the front page which was all that was needed because a relationship had already been established with researchers. In the development of a relationship, detailed reports such as those presented in the Appendix may influence the perception of reputation and quality analysis.

Farmer F expects spatial analysis services to be conducted by private sector firms, maybe farmers with the expertise and interest. Fee structures are most likely on a per acre basis or at least will be discussed on a per acre basis with a time commitment of between one and two days to perform analysis.

Farmer W

Farmer W is a sole proprietorship in Hardin County, Kentucky. Farms are rolling hills with eroded hilltops and depression areas prone to drown outs in wet years. This extreme variability in soils and topography influences yield response by weather year interaction. Farmer W has been practicing no-till production for 20 years; however, many fields were extensively tilled prior to Farmer W management. Crops grown include corn and soybean. Farmer W is self described as being skeptical and paying no attention to testimonials for products or services. One characteristic that distinguishes him from many other farmers is his preference to "watch his child’s soccer game rather than sit on a tractor.” Farmer W has been a research collaborator since the inception of this project.

Annual production decisions are made by Farmer W with longer term and economic decisions made jointly with his wife. Both have advanced degrees in Agricultural Economics from Purdue University and continue to closely collaborate with both Purdue University and University of Kentucky where Farmer W earned his B.S. Farmer W stated that the first piece of farm machinery purchased was a personal computer in 1986 with Internet and email being used for the last four years.

Yield mapping has been conducted for 11 years and farm mapping software for four years with FarmWorks and JDOffice. Yield monitor data are not used for land leasing arrangements because landowners “prefer traditional methods and are untrusting of technology” and “favor weigh scale tickets.” Farmer W had one of the first lightbars nine years ago and began using automated guidance two years ago. Variable application rates have been widely used with both GPS and pre-GPS technology. Lime has been applied at varying rates within some fields for more than 20 years. Nitrogen, phosphorus, and potassium fertilizer applications have been applied at varying rates for more than seven years. Variable seeding rates have been applied over the last eight years. Intensive on-farm trials have been conducted over the past four years in conjunction with university researchers. Corn hybrids and nitrogen rates are on-going experiments. Current on-farm trials include soybean seeding rates.

Comparison Case Study Group

Two farmers were interviewed that have not received a spatial analysis report; however, for many topics they were not expected to differ from the reference group farmers. Comparison group farmers may be positioned in the spatial analysis adoption curve where the reference group farmers were at the beginning of this project. As for adoption and use of precision agricultural technologies including conducting on-farm trials, no difference was expected between the groups.

Farmer P

Farmer P farms as a partnership between three brothers in Nelson County, Kentucky all of which have at least a four-year college degree predominately from University of Kentucky. The farm fields are rolling hills with eroded hilltops. Farmer P has not been directly associated with this project but has been discussing spatial analysis with researchers since summer 2005 and agreed to collaborate, however no spatial analysis reports have been prepared due to timing of the on-farm trial dataset. The interviewee has been farming full time for six years as a third generation farmer. Farm management and production decisions are made among family members.

Farmer P has been using computers for farm management for 27 years, with internet over the past ten. Yield mapping was first conducted 12 years ago with farm mapping software five years later including SSToolbox, FarmWorks, and JDOffice. Manual lightbar navigation was used four years ago with automated guidance used on equipment for the last two years. Variable rates of lime and seeds have been used for eight and 10 years, respectively. On-farm trials have been a management practice for 10 years. Farmer P was noted as suggesting to other farmers to “not get in a hurry when implementing and harvesting the experiment” and that “garbage in equals garbage out” when it comes to analysis and making decisions. Yield monitors have not been used for crop shares or other leasing arrangements.

Farmer T

Farmer T is a sole-proprietorship in Southwest Ontario, Canada. Crops grown include corn, soybean, dry edible beans, and wheat. The farm was considered to be an innovator with the first automated boom sprayer in Ontario, mapping yields for 13 years, and using farm mapping software for 12 years. Manual lightbar navigation has been used for four years and automated guidance for two years. Variable rates of nitrogen, phosphorus, and potassium fertilizer have been used for eight years.

Farmer T earned a B.S from University of Guelph and an advanced degree in Agricultural Economics from Purdue University where he began using computers and internet extensively 17 years ago. Farm mapping software currently includes FarmWorks, SMS Advanced, and AgLink with local access to services using SSToolbox. Locally developed accounting software tracks financial information.

On-farm trials have been conducted for the 12 years that Farmer T has operated the farm. Previous on-farm tests include nitrogen rate trials, corn hybrid and soybean varieties, and tillage. The farm is considering performing experiments on rotations with cover crops and using instantaneous protein sensors in the combine harvester to monitor wheat quality. Specific fields had electromagnetic induction and elevation measurements taken to support on-farm research.

Farmer T has agreed to collaborate with this project, although no spatial analysis reports have been prepared due to timing of on-farm trials and data for a full experiment not yet being collected. Farmer T suggested that spatial analysis service representatives visit each farm to plan upcoming experiments and discuss trials that were underway. Since many trials do not go as planned, the discussion would include what was actually implemented and what testable question could be evaluated. Farmer T made the distinction that “experts” were preferred to “consultants” and was self described as being skeptical. Farmer T stated that the ideal service would be of such quality that the service would be selective with respect to clientele.

Case Study Results

The previous sections presented the case study evidence from each farmer. This section addresses the cross-case synthesis analysis between case study farmers and between groups when warranted, provides a description of the hypotheses tested and compares case study results from three previous studies (Daberkow and Fernandez-Cornejo, 2006; Fountas et al., 2005; Urcola, 2003). The Daberkow and Fernandez-Cornejo (2006) study reported the 2002 USDA-ARMS. Fountas et al. (2005) reported a mail survey administered to farmers in Denmark and the eastern U.S. Cornbelt on perceptions of precision agriculture data handling. Urcola (2003) was the base with which this research built upon and examined ten Indiana farmers' use of combine yield monitors in their decision making processes.

On-farm Trials and Yield Monitors

Uses of yield monitors were evaluated to describe how farmers used the technology and to assign individual farmers to an appropriate position on the adoption curve. Farmers often find uses for products that industry and universities do not anticipate.

The farm management decision making process was evaluated for farmers using yield monitors to collect on-farm trial data. Although four out of five case study farmers used multiple sources of qualitative and quantitative information for their decision making process, most farmers placed the majority of the decision on only two or three sources. Farmer D relied on on-farm trials as his primary information source rather than on the suggestions of advisors which were used by the other four farmers. However Farmer D did state that decisions were made along with his dealer. Therefore, hypothesis H1 that farmers use a combination of sources of qualitative information in making decisions: experience, crop consultants, university Extension, dealerships, and other farmers was supported by two of the three reference group farmers and both comparison group farmers (**Table 1**).

Table 1: Case Study Hypothesis Testing

Reference Group			Comparison Group	
D	F	W	P	T
H1: farmers use a combination of sources of qualitative information				
NS	S	S	S	S
H2: farmers use quantitative information from off-farm yield trials				
NS	S	S	S	S
H3: farmers have more confidence with spatial analysis				
S	S	S	NA	NA
H4: farmers value yield monitor data on their own farms				
S	S	S	S	S
H5: farmers using yield monitors have dropped the use of other methods				
S	NS	S	NS	S
H6: GPS-enabled navigation technologies impact on-farm trials				
S	S	S	S	S
H7: analysis of hybrid trials must be completed prior to end of year				
S	S	S	S	S
H8: the timeliness of analysis results are as important as content of				
NS	S	S	S	S
H9: printed yield maps have no value				
S	S	S	S	S
H10: farmers prefer to make on-farm comparisons in large blocks				
S	S	S	NS	NS
H11: farmer relationships with university Extension were strengthened				
S	S	S	S	S
H12: farmers are willing to participate in regional research project				
S	NS	NS	NS	NS

S: Hypothesis supported
NS: Hypothesis not supported
NA = Not applicable due to unable to test

All case study farmers valued their yield monitor data for on-farm trials to quantify variability within and between treatments and to compare their results with industry and university claims for products on their own farms. Thus, hypothesis H2 that farmers use a combination of sources for qualitative information for decisions was supported by two of the three reference group farmers and both comparison group farmers. Hypothesis H3 that farmers value yield monitor data on their own farms because of localized yield response was supported for all farmers.

Topics related to spatial analysis were only discussed with the reference group farmers. All three reference group farmers stated that their confidence in on-farm trial results and subsequent farm management decisions increased (Table 2). Spatial analysis increased the confidence that case study farmers had in their experiments, data, and decisions. Increased confidence led to decisions being made faster and more decisions being made. Farmer D and Farmer W were more confident about answers and data from experiments, which Farmer D feels is very important. Farmer F has had increased confidence in on-farm trials after being reduced due to earlier failures. Farmer D is more likely to take action and stated that he not only makes decisions faster but also makes more decisions than before spatial analysis. Farmer W added that he thinks about on-farm trials differently now and is always considering what other experiments can be conducted (Table 2). Hypothesis H4 that farmers had more confidence in their on-farm trials analyzed with spatial analysis methods was supported.

Reference group farmers have dropped the use of previous forms of yield measurement, e.g. weight wagons, in favor of yield monitors to measure on-farm trial yields. However one comparison group farmer stated that weigh wagons would be used until yield monitors became more reliable. Therefore hypothesis H5 that farmers using yield monitors associated with a GPS have ceased use of other yield measurement methods used to measure within field yield was supported for two of the three reference group farmers and one of the comparison group farmers.

The five case study farmers are part of the early adopters of precision agriculture category that Griffin et al. (2004) reported as 13.7% of 2001 corn planted acres and 10.7% of 2002 soybean planted acres was harvested with a combine with a yield monitor associated with a GPS unit. Daberkow and Fernandez-Cornejo (2006) reported that 43% of 2002 USDA-ARMS respondents used their GPS and yield monitors to conduct on-farm experiments. All subjects of this case study research have GPS yield monitors and can only be directly compared with a subset of the Daberkow and Fernandez-Cornejo's (2006) results rather than the whole. Daberkow and Fernandez-Cornejo (2006) report that the most common use of the combine yield monitor was to monitor crop moisture whether the yield monitor was associated with a GPS or not at 68% and 87% of respondents, respectively. At least one of the five case study farmers directly used the moisture sensor in decision making, i.e. Farmer D and popcorn quality.

Daberkow and Fernandez-Cornejo's (2006) results and Urcola's (2003) hypothesis 5.1 with three out of five of his case study farmers used yield monitors as the sole yield measurement tool, i.e. ceased to use weigh wagons and/or scales, supported the findings of this case study research. In addition, Urcola (2003) stated that four out of five case farmers using GPS yield monitors valued their own yield data because of localized environmental response differences.

Urcola's (2003) groups differed by the relevance of on-farm trials in their farm management decision making process. Four out of five farmers with yield monitors used on-farm trials as a primary source of quantitative information for selecting hybrids and varieties (Table 2). None of the farmers without a yield monitor used their on-farm trials as a main information source in selecting hybrids. Farmer D used on-farm trials and yield monitor data as his primary source of quantitative information while the other case study farmers used their on-farm trial data as a major source of production information.

Both the ARMS survey and this case study research indicate leasing negotiations and splitting crop shares are not common uses of yield monitors. As opposed to suggested potential uses of the yield monitor for farmland leasing arrangements, only 9% of ARMS respondents used GPS yield monitors for farmland lease negotiations and 6% for dividing crop shares. None of the case study farmers used yield monitors for leasing arrangements. The closest example to leasing arrangements was Farmer W and Farmer T using precision agriculture technologies to measure field boundaries with GPS to determine tillable acreage for purposes of cash rent bids on new land and other acreage verification purposes. Farmer W went on to suggest that most landowners do not trust precision agriculture technologies and that weigh scale tickets are still the standard in splitting crop shares.

In a 2004 survey, most U.S. farmers (87%) gathering precision agriculture data made at least some changes in farm management practices while less than 10% made substantial changes to their operation (Fountas et al., 2005). Of the farmers in their survey who have been using precision agriculture for more than five years, 42% stated yield maps were very useful while the percentage dropped to 10% for these farmers with less experience (Fountas et al., 2005). Urcola (2003) found that only two out of five case study farmers were satisfied with yield map information. Fountas et al. (2005) also indicated that soil maps tend to be printed to paper more often than yield maps. Reaffirming Urcola’s (2003) assertion that subjective visual observation was the most common method to analyze yield monitor data, Fountas et al. (2005) reported that more than 75% of farmer respondents printed yield maps with 13% never printing yield maps.

Like farmers studied by Urcola (2003) and Fountas et al. (2005), none of the case study farmers placed significant value on printed yield maps.

GPS-enabled Navigation Technologies

Embodied-knowledge precision agriculture technology such as GPS-enabled navigation technology has had a higher adoption rate than the information-intensive technologies, e.g. yield monitors and variable rate applications (Griffin et al., 2004). Since these navigation technologies have increased the ease with which field operations can be conducted, it was suspected that implementing and harvesting of on-farm trials would also be impacted.

Case study farmers stated that whole-farm profitability of GPS-enabled navigation technologies was evident during the farm planning process and was realized immediately after implementation. As expected, the availability of GPS-enabled navigation technologies positively impacted on-farm trial implementation and harvesting (Table 4). Farmer P stated that GPS guidance has not affected on-farm trials yet but “it will” in the future for both implementation and harvesting. Planting on-farm trials and recording treatment locations became automated with GPS and automated controller software. During the implementation phase, GPS-enabled navigation technologies reduced guess rows for split-planter trials as well as other spatially sensitive treatments. GPS guidance on combines helps ensure consistent header widths especially for crops not planted in rows, e.g., soybean, wheat, and rice which are important to accurate yield monitor measurements and associated per unit area calculations. Therefore hypothesis H6 that GPS-enabled navigation technology impacts on-farm trials was supported for all farmers from both groups.

Spatial Analysis Service

Measuring the benefits of spatial analysis services were key to this research. Farmer perceptions of spatial analysis results, the reports, and services associated with the analysis were evaluated to make suggestions to the agricultural industry and/or university Extension programs considering offering these services.

Differences existed between reference group and comparison group farmers with respect to the criteria of a full-service spatial analysis service. The ideal service from the reference group farmers' perspective would include assistance with 1) planning and designing the experiment, 2) prescription for inputs, 3) calibration and operation of yield monitor, 4) interpreting results of study, 5) economic analysis, and 6) decision making (Table 5). Planning and designing experiments may include advice on what treatments and rates to test. The experimental design must be individually created for each field-experiment combination such that each treatment is represented on each major productivity zone. Farmers also asked for advice on proper calibration and operation of the yield monitor. When on-farm trials are harvested, greater demands are placed on the yield monitor than when harvesting remaining farm acreage. Rather than casual on-screen observation, printed yield maps, or rudimentary analysis, the yield monitor data collected during harvest of on-farm trials is used to determine treatment differences and make farm management decisions thus accuracy and precision of yield monitor measurements are more important than while harvesting other non-comparison fields. Once data are analyzed and results presented, farmers requested assistance with interpretation of statistical inference results, economic analysis, and associated farm management decision making. While the choice of statistical model was not of interest to all farmers, the interpretation of the statistical output was important.

The spatial analysis reports, whether prepared by analysts or automatically generated by software, would include yield and economic analysis plus statistical confidence levels. Farmer F stated the final answer is all that is needed. Farmer W reiterated timeliness was more important than details, especially for hybrid trials. Therefore, hypothesis H7 that completion of analysis by end of current year was supported for all farmers. Hypothesis H8 that timeliness was as important as content were supported for two of the three reference group farmers and both comparison group farmers. Case study subjects of this research agreed that printed yield maps had little value, especially when additional analysis capabilities could be conducted electronically, thus hypothesis H9 that printed yield maps have limited value was supported for all farmers.

Although Fountas et al. (2005) reported that the most requested information by Danish farmer-respondents were yield map interpretation, U.S. counterparts did not make a request for yield map interpretation. In addition, 22% of U.S. farmer-respondents stated that yield maps were difficult to interpret while only 10% stated that soil maps were difficult to interpret and roughly one-fourth stated that both yield maps and soil maps were very easy to interpret (Fountas et al., 2005). Three of Urcola's (2003) farmers stated that interpreting yield maps was confusing and basing farm management decisions on yield maps was difficult. Reference group farmers requested additional assistance with yield data interpretation especially on interpreting statistical results, again indicating that case study farmers differed from most farmers. Fountas et al. (2005) went on to say that U.S. farmer-respondents requested that precision agriculture specialists and service providers to 1) support the use of gathered data, 2) provide economic analysis, and 3) provide VR applications. All farmers from both case study groups requested economic analysis including partial budgets and sensitivity analysis.

Experimental Designs

Case study farmers wish for experimental designs that are simple to plan, do not cause excessive yield penalties to implement or harvest, are easy to implement and harvest, and provide data suitable for making farm management decisions. In order for an experimental design to provide useful information, variability must be isolated and each treatment is required to be adequately represented on each major productivity zone. Each candidate experimental design offers specific advantages and disadvantages that differ by treatment, farmer, equipment configuration, and management practice. Farmer D desires experimental designs that require less time to implement that provide reliable and reproducible data (Table 4). Farmer W desires experimental designs that are easy to plant, implement, and analyze. Farmer W went on to say that if experimental designs increase time requirements, then that is "going backwards."

Farmers from both groups were critical of the small-plot and strip-trial designs derived from classical statistics. Farmers stated that they would not use small-plot experimental designs because of excessive time requirements, non-representative of field-scale conditions, or excessive cost. Farmer D and Farmer T stated that split-planter trials do not always work well for their equipment configurations. Farmer F is concerned about treatment edge effects and application drift masking true treatment differences, an idea communicated by an industry representative conducting on-farm trials. Farmer P stated that strip-trials are difficult to analyze if not mapped properly.

Although split-field large treatment block designs are more accepted now than before this project, these designs are not perfect. Farmer W stated split-field trials are "more difficult to compare apples to apples" and some replication is usually needed to collect ample yield monitor data from each treatment-zone combination.

There were differences between the reference group farmers and comparison group farmers with respect to preferred experimental designs. One difference between reference group and comparison group farmers was that reference group farmers have reduced the proportion of experiments in split-planter or strip-trial designs in favor for split-field designs (Table 4). Although reference group farmers felt confident that their split-field experimental design data provided information suitable for farm management decision making as long as each treatment was present on every major productivity zone in the field, comparison group farmers preferred the numerous replications of classical split-planter designs to isolate as much variability as possible. However, comparison group farmers acknowledge the costs of the design with respect to agronomic and analysis problems. Hypothesis H10 that farmers prefer to make on-farm comparisons with large block split-field designs was supported for all three reference group farmers and not supported for both comparison group farmers.

Urcola (2003) found that six out of ten case study farmers desired to compare hybrids in large split-field blocks rather than strip-trial designs. All three reference group farmers preferred larger block experimental designs. Urcola (2003) stated their rationale dealt with lower time requirements. Urcola's (2003) four case study farmers using strip-trial designs cited the spatial variability influencing treatment evaluation of split-field designs as the primary disadvantage.

Role of University Extension

University Extension topics were included in this case study to evaluate 1) if perception of farmer-Extension relationships changed during this project, 2) what role university Extension may play in spatial analysis and interpretation, and 3) if regional on-farm trials would be the natural next step to spatial analysis of on-farm trials.

Farmer P and Farmer W were different themselves from the rest of the subjects by suggesting Extension have an instrumental role in on-farm research including recommendations on experimental designs (Table 2). This potentially may be associated with their relationships with the local university being potentially different from the relationships the other farmers had with their local universities. Farmer W stated that he liked the multiple university involvement on his farm. It was expected that reference group and comparison group farmers differed due to participating with the SARE project. Although reference group farmers stated an improved relationship with university Extension especially with individuals including this researcher resulted from participation with this project, comparison group farmers already had close working relationships with multiple universities and stated improved relationships with this researcher; thus H11 that farmer relationships with university Extension were strengthened from involvement in this project was supported for all farmers.

Some case study subjects suggested that Extension may facilitate much of the opportunity that exists in on-farm trials and spatial analysis including: 1) organize farmer peer group meetings similar to marketing clubs, 2) maintain network of farmers across regions to share information and participate in regional research projects, and 3) link to applied researchers. The benefits of Extension facilitating the spatial analysis service include access to unbiased expertise in an existing structure and associated support staff as well as graduate and post-doctoral researchers. All case study subjects valued the direct linkage with applied university specialists and researchers. However, case study farmers did not suggest spatial analysis would be directly offered by university Extension programs, a least in the traditional sense of Extension.

Case study farmer interest in participating in regional on-farm trials was not clear. Farmer D was very interested in regional on-farm trials; potentially to determine if his localized response differs from other regions. Farmer F was not interested in participating in formal regional on-farm trials, but values having a network of colleagues with which to share information. Farmer W was willing to participate, but did not seem to have increased interest in regional on-farm trials. Hypothesis H12 that farmers were more willing to conduct and participate in regional on-farm experiments was supported for one reference group farmer and not supported for both comparison group farmers.

The role of Extension specialists may be to facilitate a network of peer farmer groups conducting participatory on-farm research. Although Extension would provide the basic network of peers, personal relationships between farmers would be built outside of the Extension framework. Extension professionals would also provide recommendations on specific experimental design layouts relative to the study field, treatments, and farm management practices. The spatial data analysis service will most likely be at least facilitated by Extension and possibly offered as an Extension program due to high costs of specialized human capital in the form of researchers and staffing.

Spatial Analysis Reports

The spatial analysis reports were evaluated to determine the most important content in order for future services to provide information useful to innovative farmers. Farmer D suggested adding information on interpreting statistical analysis results (Table 5). Although the request for additional training on interpretation by Farmer D dealt specifically with spatial analysis interpretation, the comment can be generalized to all agricultural research. The role of Extension teaching interpretation of analysis results should be revisited with respect to statistical analysis (Griffin and Lambert, 2005).

Farmers D and W expressed interest in and appreciation for the yield monitor data filtering procedure. Farmer W suggested more information on the process and benefits of the process as well as the costs of not filtering the data. A similar inquiry on the cost of using non-filtered yield monitor data was made at the Yield Monitor Data Analysis Workshop.

Both of the comparison group farmers suggested georeferenced weather data would be useful in spatial analysis reports, while none of the reference group respondents mentioned weather. Farmer T added that input application formulas, i.e. prescriptions, and economic analysis are useful to his decision making (Table 5).

Case Study Summary

Case study subjects were chosen based upon their experience with on-farm testing and willingness to cooperate with this research in on-farm testing, data, and participating in follow-up interviews. Results indicate that reference group farmers had more confidence in their farm management decisions based upon on-farm trial data than comparison group farmers. Not only did reference group farmers make decisions quicker, but they made more decisions than they would have without spatial analysis. Reference group farmers requested additional training in interpreting statistical analysis results.

Major differences occurred between reference group and comparison group farmers for their choice of field-scale experimental design. Reference group farmers opted to use large treatment block split-field designs with limited replication that reduced the cost of doing on-farm trials, while comparison group farmers chose strip-trial designs with many replications based on classical agronomic statistics. Training and experience in the SARE project gave them confidence in their ability to extract useful management data from the low cost large plot designs.

Limitations of This Case Study

Since this research built relationships with each case study subject and also took the role of direct observer and interviewer, a level of intervention occurred with respect to interviewee response and behavior. Because the case study farmers were considered innovators in utilizing precision technology for on-farm testing, a comparison to typical farmers were not possible. However, insights gathered from case study research are useful in developing formal surveys to be administered to a larger sample of farmers concerning their use of precision agricultural technologies and on-farm testing.

Future Research

Case study results gave indication for further study and provided sufficient information with which to create a survey instrument to be administered to a larger sample of farmers coming from a wider range of experiences and technology adoption. These survey questions could be assimilated with the USDA-ARMS survey to increase effectiveness and prevent producers from being repetitively surveyed.

A market study to determine the value of a spatial data analysis service to farmers, the fees farmers are willing to pay for such a service, and the revenue to attract analysts would be beneficial. In addition, the value that farmers place on their production records and data would be important to estimate. Although the spatial data analysis service suggested in this research would not be widely applicable to the pool of current farmers, it is expected that a proportion of farmers at a future date would desire appropriate spatial data analysis. At the current time, there are some farmers who would benefit from this level of analysis however it is uncertain if they would ultimately be willing to pay the fees necessary to persuade qualified analysts to offer said services.

Acknowledgements

A United States Department of Agriculture – Sustainable Agriculture Research and Education (USDA-SARE) Graduate Student Grant Program project number GNC03-020 entitled "Development of Appropriate Participatory On-Farm Trial Designs for Sustainable Precision Agriculture Systems" provided funding to facilitate this research.

References

Anselin, L. 2003. GeoDa 0.9 User's Guide. Spatial Analysis Laboratory, University of Illinois, Urbana-Champaign, IL. On-line at: https://www.geoda.uiuc.edu/. Accessed May 8, 2007.

Antle, J.M. and Pingali, P.L. 1994. Pesticides, Productivity, and Farmer Health: A Philippine Case Study. American Journal of Agricultural Economics. 76(3) pp. 418-430.

Boland, M., Katz, J., and Barton, D. 1999. Case Studies on Food and Agribusiness Closed Membership Cooperatives. MF-2448.

Daberkow, S. and Fernandez-Cornejo, J. 2006. Yield Monitor Adoption and Information Use by U.S. Soybean Producers. Selected paper presentation at the 2006 Southern Agricultural Economics Association Annual Meeting in Orlando, FL February 6 – 8, 2006.

Dorward, P. Galpin, M. and Shepherd, D. 2003. Participatory Farm Management Methods for Assessing The Suitability Of Potential Innovations. A Case Study on Green Manuring Options for Tomato Producers in Ghana. Agricultural Systems 75 (2003) 97–117

Doye, D., Jolly, R., Hornbaker, R., Cross, T., King, R.P., Koller, E.F., Lazarus, W.F., and Yeboah, A. 2000. Case Studies of Farmers' Use of Information Systems . Review of Agricultural Economics, December 2000 - Vol. 22 Issue 2 Page 292-613.

Fountas, S., Blackmore, S., Ess, D. Hawkins, S., Blumhoff, G., Lowenberg-DeBoer, J. and Sorensen, C.G. 2005. Farmer Experience with Precision Agriculture in Denmark and the US Eastern Corn Belt. Precision Agriculture, 6, 121-141.

Griffin, T.W. 2006. Decision-Making From On-Farm Experiments: Spatial Analysis of Precision Agriculture Data. Purdue University, Ph.D. Dissertation.

Griffin, T.W. and Lambert, D.M. 2005. Teaching Interpretation of Yield Monitor Data Analysis: Lessons Learned from Purdue's 37th Top Farmer Crop Workshop. June, 2005. Journal of Extension. On-line at: http://www.joe.org/joe/2005june/iw5.shtml Last accessed May 8, 2007.

Griffin, T.W., Lowenberg-DeBoer, J., Lambert, D.M., Peone, J., Payne, T., and Daberkow, S.G. 2004. Adoption, Profitability, and Making Better Use of Precision Farming Data. Staff Paper #04-06. Department of Agricultural Economics, Purdue University. On-line at: http://agecon.lib.umn.edu/

Grisso, R.D., Jasa, P.J., Schroeder, M.A., and Wilcox, J.C. 2002. Yield Monitor Accuracy: Successful Farming Magazine Case Study. Applied Engineering in Agriculture. Vol. 18(2): pp 147-151.

Harling, K.F., and Akridge, J. 1998. Using the Case Method of Teaching. Agribusiness, Vol. 14, No. 1, 1–14.

Harling, K. and Miser, E. 19980 Case Writing: An Art and a Science. International Food and Agribusiness Management Review, l(1): 119-l 38.

Malcolm, L.R. 2004. Farm Management analysis: a core discipline, simple sums, sophisticated thinking. Australian Farm Business Management Journal, 1(1):45-56.

Popp, J., Griffin, T., Pendergrass, E. 2002. How Cooperation May Lead to Consensus
Assessing the Realities and Perceptions of Precision Farming in Your State. Journal of the American Society of Farm Managers and Rural Appraisers. 65(1) pp.26-31. Available on-line at: http://www.asfmra.org/documents/popp26_31.pdf Accessed September 28, 2006.

Urcola, H. 2003. Economic Value Added by Yield Monitor Data from the Producer's Own Farm in Choosing Hybrids and Varieties. Purdue University, M.S. Thesis.

Westgren, R and Zering, K. 1998. Case Study Research Methods for Firm and Market Research. Agribusiness, Vol. 14, No. 5, pp. 415-424.

Yin, R.K. 2003. Case Study Research: Design and Methods (3rd ed.). Beverly Hills, CA: Sage Publishing.

Table 2: Reference Group Farmers' Response to Selected Spatial Data Analysis Questions

Question	D	F	W
How has your involvement changed the process of steps in which you make decisions?	Feel better and more confident about answers, which is very important. Added validly to results and More likely to take action rather than sitting on the fence	Not a lot.	I think about on-farm trials differently and always thinking about what other experiments can be done. Spatial analysis allows statistical validity.
How has your perception of on-farm trials changed?	No more traditional small replicated plots; all on-farm trials are conducted with the yield monitor	Not much, still see as useful.	I have more confidence in my data from the yield monitor
How has your level of confidence in on-farm trial results changed?	Gone up a lot	Gone back up after some failures prior to this project.	Confidence increased because of analysis rigor
How has your level of confidence in your farm management decisions made from on-farm trial data changed?	Gone up a lot	A little nervous the first year implementing lower soybean seeding rates, but very confident now.	More confident
What specific changes have you made to your production practices?	Lowered soybean seeding rates across the farm, questioning P and K fertility rates, and making my hybrid selection much faster	Lowered soybean seeding rates to 130K seeds per acre on most soils and 150K on eroded hilltops.	Eliminated one company's line of hybrids
What is the role of Extension?	Supporting role like in marketing clubs, maybe develop yield monitor data analysis clubs by facilitating and setting up farmer peer groups	Doubtful local Extension would have a role or facilitate spatial analysis or farmer peer groups. Farmers contact individual professors for specific issues.	Recommendations on experimental designs

Table 3: Response to Selected Questions on Yield Maps, On-Farm Trials, and Advice for Other Farmers

	Reference Group			Comparison Group	
Question	D	F	W	P	T
What is the value in printed yield maps?	Better than watching yield monitor numbers from the combine, just pictures	None if have good sized computer monitor. Maybe take to landlord to discuss improvements.	Remind of costs and returns on marginal land	Identify areas needing more management	No need for paper yield map. Value in maps on the computer screen
How do on-farm trials fit in as part of your production information?	Primary data for decision making	Small tests prompted to begin strip-till system and use RTK automated-guidance	Verifies intuition	With a careful conservative approach. Continue to evaluate proven sustainable ideas.	Add to information base. After two years of promising data, do a third year and maybe implement on fourth year.
What is the value in a regional research project?	I would like for it to happen	Always good to have more information but would rather have colleagues to contact with questions than formal experiments	Verifying practices	Extremely high value	Important to share knowledge two-directionally

Table 4: Farmer Statements Regarding Experimental Designs

	Reference Group			Comparison Group	
Question	D	F	W	P	T
What characteristics of your experimental designs do you like the most?	Large split-field blocks take less time to implement	Ease of design, implementation, harvest, and analysis	Ease of planting and separating treatments in split-field large blocks	Replications with strip-trials	Isolate variability.
What characteristics of experimental designs do you like the least?	Small-plots take too much time. Split-planter trials do not work well for 8-row planter and 8-row combine	Treatment edge effects and drift from strip-trials interfere with trial. Split-field needs some replicates on the high variability of field.	Split-field large blocks more difficult to compare apples with apples and have to make sure all treatments are on all zones with highly variable soils	If strip-trials are not properly mapped, very hard to determine yield data. Must stay organized with strip-trials	
What characteristics make the ideal experimental design?	Less time to implement the better. Reliability and reproducibility of results.	Impose each treatment on each representative area of field	Easy to plant and apply treatments. Easy to analyze data. Minimal time requirements; if affecting timeliness due to implementation, going backwards.	Strip-trials with weigh wagon check or good yield monitor would be better	Field-scale real-world conditions. Small-plots are not representative.
How does GPS-enabled guidance affect on-farm trials?		RTK required for deep placement of P & K for strip-till. Allows to micro-manage production.		Not yet, but will.	

Table 5: Farmer Comments on Spatial Analysis and Decision Support Systems

	Reference Group			Comparison Group	
Question	D	F	W	P	T
Who do you expect to perform the software portion of spatial analysis of on-farm trials?	The farmer	The farmer, some farmers may outsource.	Extension because unbiased. Do not want to send hybrid trials to seed companies.	The farmer depending upon the skill level and interest of farmer. Probably consultants or Extension.	Centrally located lab anywhere in the world with expertise. Some large may have someone in-house to perform spatial analysis. The latest research would be associated with university Extension.
What would an ideal full service spatial analysis service provide?	Decision making.	Plan and design experiment. Provide prescription for inputs and recommendations. Assist calibration of yield monitor.	Design experiment, advice on running yield monitor, interpretation of results	Field by field reports with field and zone averages	Soil tests, across soils analysis, and email the results. A 3-day visit to each farm to discuss “these are the trials we are doing and this is what we have really done.” Send yield data to lab after harvest and receive a 2-page report with economic cost:benefit analysis. Provide a network of farmers conducting this type of research.
What capabilities would you like to see in farm-level software packages?	Spatial statistical analysis	Economics.	Provide output similar to spatial analysis reports. Interpretation of data.	Accounting and cost integrated into GIS	Standardized hardware, software, and communication protocol. A seamless system preferably in a single software rather than the 3 or more it currently takes.
What reports or recommendation from spatial analysis would be the most valuable to you?	Anything adding validity. A confidence level from statistical inferential analysis	The final answer.	Quick turn-around is most important, especially for corn hybrid decisions. Yield analysis and economic analysis.	Whole-farm crop information by soils by variety, georeferenced weather information	Sensitivity analysis, regression formula with payback analysis. Correlate precision agriculture data to real-world weather data. Several farmers geographically dispersed in a network of peer support would serve as replicate in research trials.
What would you expect to pay for full-service spatial analysis?	$3 per acre	$5 per acre or $500 flat fee per experiment. Doubtful to be percentage of expected value.	Depends on importance of information to decision making. Maybe a percentage of predicted value. For quick turn-around time up to several hundred dollars.	$2 per acre. Maybe on a per experiment basis up to $500.	$5 to $10 per acre or 40 to 50% of payback which would be a function of treatments and returns.

Appendix A Example Spatial Analysis Report

Field: Farmer Field

Experimental design: Replicated strip-trial design

Treatments: Five soybean seeding rates

Crop year: 2004 soybean

Summary:
Soybean yields were highest on Starks-Crosby and lowest on Martinsville-Ockley soil. The Fincastle-Miami soil responded similarly to Starks-Crosby although minor differences were documented including a slightly higher but significantly different optimal seeding rate. Results of this study suggest that soybean seeding rates may be as low as 110 to 120K seeds per acre and still be maximizing profits. However, sensitivity tests suggest non-optimum seeding rates may not adversely affect yield although profitability is affected by over-application of seeds.

Disclaimer:
This study is only one site-year. Multiple years and/or site-years would be necessary to make long-term decisions especially for rate trials. However, results from studies such as this one gives some amount of indication and provides direction with which to conduct further experimentation. In addition, on-farm testing is not meant to be generalized across regions beyond some reasonable distance which may only include adjacent fields.

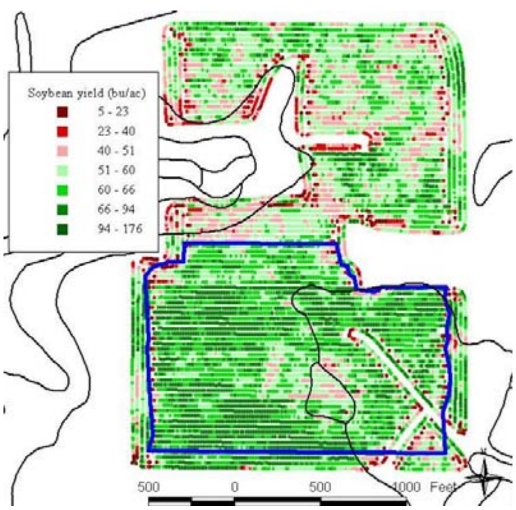
Report prepared by:

Terry Griffin
Purdue University
765.586.2385
twgriffi@purdue.edu
July 28, 2006

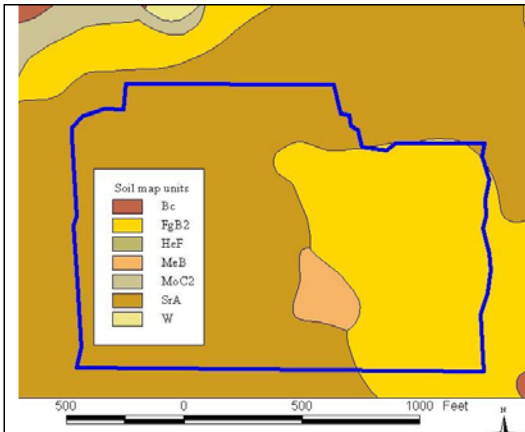
Field Study and Goal

This report concerns the 2004 soybean seeding rate trials on a portion of the Burkett Field (Map 1a). The overall goal of this experiment was to determine if current seeding rate applications were suitable for soils on this farm under current management practices. In general, agronomic information from several Midwestern states suggests that 100K 'evenly distributed' soybean plants at harvest are needed for maximum yield in drilled soybeans (Conley and Shaner, 2006). For 15 and 30 inch row spacing, a minimum of 80K plants per acre at harvest maximizes yield (Conley and Shaner, 2005). Current Purdue recommendations are 145.2K and 116.2K seeds per acre for 15 and 30 inch rows, respectively. Conley and Shaner report that survey results suggest Indiana farmers are over-applying soybean seed. The Illinois Agronomy Handbook states that soybean seeding rates over 150K seeds per acre does not increase yield or reduce yield variability.

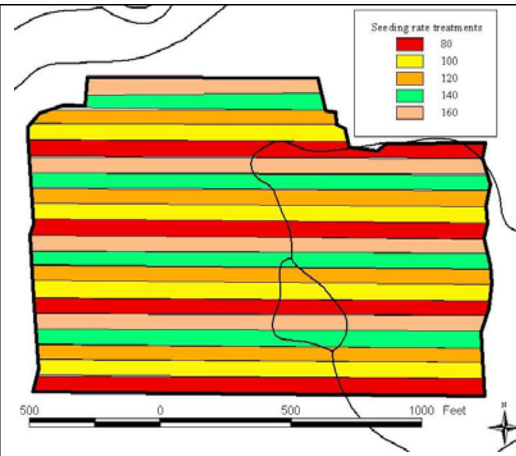
The beginning dataset includes spatially correlated yield monitor data, treatments, and elevation. Treatments of 80, 100, 120, 140, and 160 thousand seeds per acre were planted in 30-inch rows on roughly 1,740 foot long strips 24-rows or about 60 feet wide using a strip-trial design (Map 2b). This study is pertinent due to seed costs becoming a larger proportion of variable costs, changes in soybean price to seed cost ratio, and shift in cultural practices specifically weed control. Similar studies and changes to production practices are occurring across the U.S.



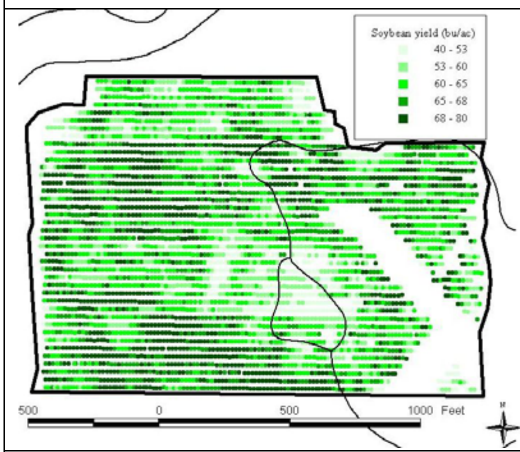
Map 1. Whole field with soils and soybean yield data



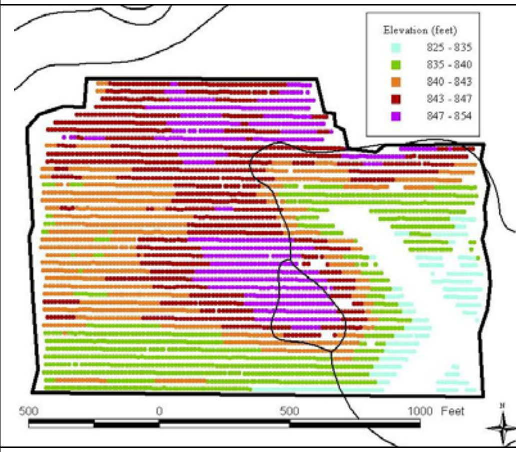
Map 2a Soil mapping units



Map 2b Soils with seeding rate treatments



Map 2c Soils with soybean yield data



Map 2d Soils and elevation

Map 2: Maps of 2004 Soybean seeding rate study

Data

The yield monitor data was subjected to a yield filtering protocol using Yield Editor from USDA-ARS to remove unreliable data (Drummond, 2006). Table 1 presents the filtering parameters and the number of observations deleted (Map 2c). Although several yield observations were omitted from the dataset due to the filtering procedure, it is believed that information was improved. For instance, when changes in harvester speed between two observations in a row are greater than 20% (smooth velocity setting of 0.2), it is expected that the harvester is not able to make correct measurements. Thus these 408 yield observations may have provided misleading information. These filtering parameters were set from a combination of prior experience and trial and error with this dataset. The resulting 3,897 yield data points are summarized in Table 2 by soils and seeding rate treatment and Map 2c.

Table 1. Parameters, criteria, and number of points deleted in yield data filtering

Filtering parameter	Parameter value	Number of deleted points[a]
Maximum velocity (mph)	5.25	8
Minimum velocity (mph)	4	1802
Smooth velocity	0.2	408
Minimum swath (in)	0	0
Maximum yield (bu ac^{-1})	80	49
Minimum yield (bu ac^{-1})	0	0
Standard deviation filter	4	1524
*Flow delay (s)	3	561
*Start pass delay (s)	4	745
*End pass delay (s)	0	0

*Flow delay, start and end pass delays of 12, 4, 4 were conducted during importing data into SMS by the farmer with additional filtering set as above.

[a] Points deleted are not cumulative, i.e. the "same" point can be deleted by multiple criteria.

Before analyzing the yields, it is important to have data explaining the spatial variability in the field. These variables are presented in Table 3 with details of selected continuous variables presented in Table 2. Soybean seeding rates were assigned to each yield observation indicating which seeding rate was represented by the yield measurement. For each soil as defined by USDA-NRCS soil maps (Map 2a), a binary variable was assigned to the yield observation. The number 1 was assigned if the yield observation was from the particular soil and the number 0 otherwise. This was conducted for all three soils; Starks-Crosby silt loam (Fine-silty, mixed, superactive, mesic Aeric Endoaqualfs; Fine, mixed, active, mesic Aeric Epiaqualfs), Fincastle-Miami silt loam (Fine-silty, mixed, superactive, mesic Aeric Epiaqualfs; Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs), and Martinsville-Ockley silt loam (Fine-loamy, mixed, active, mesic Typic Hapludalfs; Fine-loamy, mixed, active, mesic Typic Hapludalfs). The Starks-Crosby was considered the predominate soil followed by the Fincastle-Miami silt loam which represented 68.3 and 28.1% of observations, respectively. The Martinsville-Ockley soil was considered a minor soil at only 3.6% of observations and was expected to have lower yield potential than the rest of the field. Since previous research has indicated that small portions of a field may influence whole field profitability, the Martinsville-Ockley soil was given a thorough analysis.

Elevation was used as a supporting variable and obtained from the RTK-GPS measurements from the combine harvester (Map 2d and Table 2). The elevation variable provides information that may relate to depth of topsoil such as eroded hilltops and relative position in the terrain. For analysis, the elevation variable was normalized by subtracting the minimum elevation measurement from each observation although the absolute elevation is given in this report. In addition to elevation, the square of elevation was used to determine if yield responses differed over the range of observed elevation. Relative elevation was calculated by finding the localized weighted elevation (average elevation of immediately surrounding observations) and subtracting the elevation measurement from the said location. Relative elevation provides the relative micro-scale elevation (measures whether this observation was higher or lower than nearby observations).

Interaction terms between elevation, seeding rate, and soils were included to determine if treatment response varied by elevation and/or soils. All soybean seeding rates were represented across the whole topography range and all soil map units (Table 2 and Map 2b,d). However, it is questionable if adequate yield observations were collected for the Martinsville-Ockley soil and if the soil mapping units as defined by USDA-NRCS were adequately measured for the level of precision with which the data were subjected in this field experiment. An attempt to redefine soils or to delineate 'management zones' may provide more precise estimates of site-specific yield response to soybean seeding rates.

Table 2: Descriptive statistics of selected continuous variables

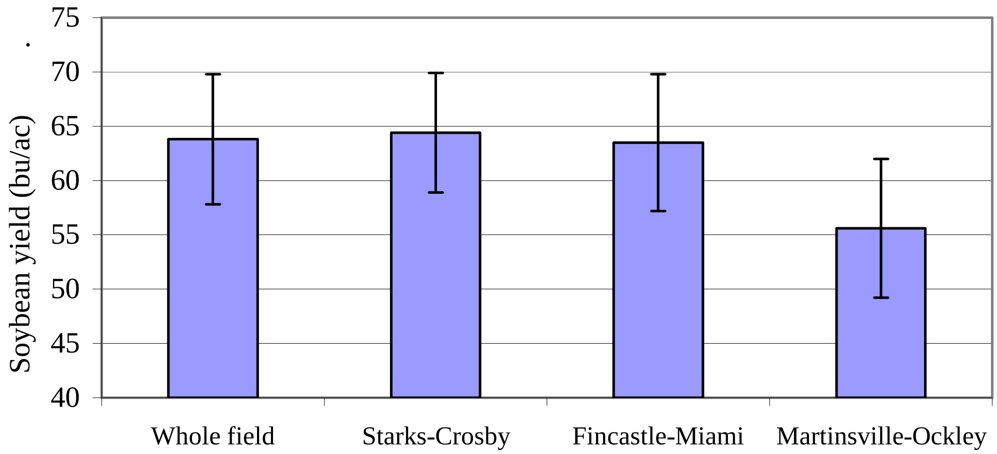
	Yield mean bu ac^{-1}	Yield std dev bu ac^{-1}	Elevation mean feet	Elevation std dev feet	Elevation min feet	Elevation max feet
Whole-field	63.8	6.0	842.2	4.6	825.5	853.4
	By soil mapping unit					
Starks-Crosby (SrA)	64.4	5.5	843.2	3.7	833.0	853.4
Fincastle-Miami (FgB2)	63.5	6.3	839.1	5.0	825.5	850.1
Martinsville-Ockley (MeB)	55.6	6.4	848.4	3.2	841.2	853.4
	By seeding rate (000's)					
80	63.9	7.0	841.5	4.8	827.1	852.0
100	63.8	5.7	841.7	5.2	825.5	853.4
120	64.0	5.7	842.0	4.7	828.7	853.4
140	64.0	6.0	842.4	4.3	828.7	851.1
160	63.3	5.2	843.9	3.5	829.1	852.0

Table 3: Description of variables

Variables	Description
POP	Seeding population in thousands
POP_SQ	Seeding population squared
SrA	Starks-Crosby soil binary variable
MeB	Martinsville-Ockley soil binary variable
FgB2	Fincastle-Miami soil binary variable
POP_MeB	Population by Martinsville-Ockley soil binary variable interaction
POP_FgB2	Population by Fincastle-Miami soil binary variable interaction
Elevation by MeB	Elevatin by Martinsville-Ockley soil binary variable interaction
Elevation by FgB2	Elevation by Fincastle-Miami soil binary variable interaction
Elevation	Normalized elevation (minimum elevation = 0) (feet)
Elevation squared	Elevation squared
POP by elevation	Population by elevation interaction
Relative elevation	Relative elevation

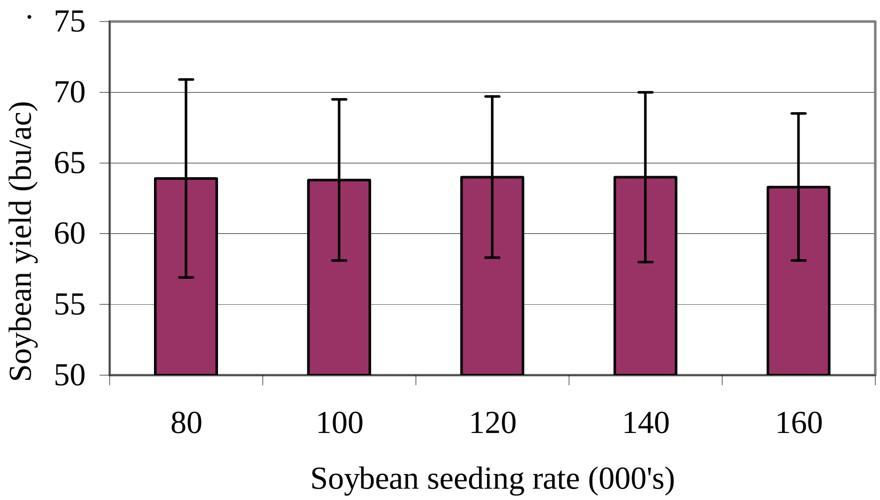
The average yield from all yield monitor observations was nearly 64 bushels per acre with a standard deviation of 6 bushels per acre (Table 2). The standard deviation of 6 bushels suggests that 99% of all observations are within plus or minus 3 standard deviations (18 bushels) of the average (45.8 through 81.8 bushels per acre) (Table 2 and Figure 1 where vertical error bars represent standard deviation). Although the Starks-Crosby and Fincastle-Miami soils had similar mean yields of 64.4 and 63.5 respectively, the Starks-Crosby had a lower standard deviation by 0.8 bushels. The Martinsville-Ockley soil had a lower yield than the other two soil map units (55.6 bushels per acre) however the standard deviation was similar to the Fincastle-Miami soil (6.3 and 6.4 bushels per acre, respectively).

Average yield is consistent across seeding rate treatments, differing by only 0.7 bu per acre across all five rates and only 0.2 bu per acre for the four lowest seeding rtes (Figure 2). Although the 160K seeding rate had the lowest mean yield, it also had the lowest standard deviation (Table 2 and Figure 2). The lowest seeding rate tested, 80K seeds, had the greatest variability with a standard deviation of 7 bushels per acre, a full bushel more than the next highest standard deviation.



Error bars represent 1 standard deviation

Figure 1. Average yield by whole field and soils



Error bars represent 1 standard deviation

Figure 2. Average yield by seeding rate

Analysis

Precision agriculture data in general are spatially correlated and are not independent. When observations are not independent, traditional analysis methods lack the ability to properly estimate the variability of the estimate (predicted yield in this case), potentially providing misleading results. However, spatial analysis methods are able to explicitly model the spatial variability and accurately estimate reliable treatment response with spatially correlated data. Analysis was conducted for both traditional and spatial techniques. Although traditional analyses are known to not provide reliable results with spatial data, the traditional analysis was conducted to demonstrate the decision that would have been made without adequate spatial analysis. Spatial analysis is conducted by taking into account the characteristics of neighboring observations. The spatial error process model was performed using the 45-meter inverse distance weights matrix and regression output presented in Appendix A.

The economic analysis results are reported in Table 4. The price of soybean was assumed to be $5.50 per bushel and soybean seed costs were expected to be $0.20 per one-thousand seeds (Table 4). Further economic analysis may be conducted by adjusting corn price and seed costs in the highlighted cells of the enclosed spreadsheet under the “Partial Budget” worksheet. The worksheet is ‘protected’ although there is no password in the event a modification is desired (additionally the request for modification can be sent to Terry who will make the changes). Agronomic and economic results are presented in the section below.

Results

Both traditional and spatial analysis results are presented to show the differences in predicted yield and decision that would have been made (Figures 3 through 5). The traditional analysis is the aspatial model which does not take into account the characteristics of neighboring observations. The spatial model takes into account the characteristics of neighboring observations by explicitly modeling the spatial structure within the model. Spatial statistical analysis results are presented in Appendix A1.

With traditional analysis, the yield response curve may not have been properly estimated (Figure 3). However, classical quadratic yield response functions were estimated as expected with spatial analysis (Figure 4) with a detailed graph in Figure 5. Optimal seeding rates varied across elevation and soils. The whole field yield maximizing seeding rate was 129K seeds per acre (agronomic rate) and ranged from 125K on Starks-Crosby

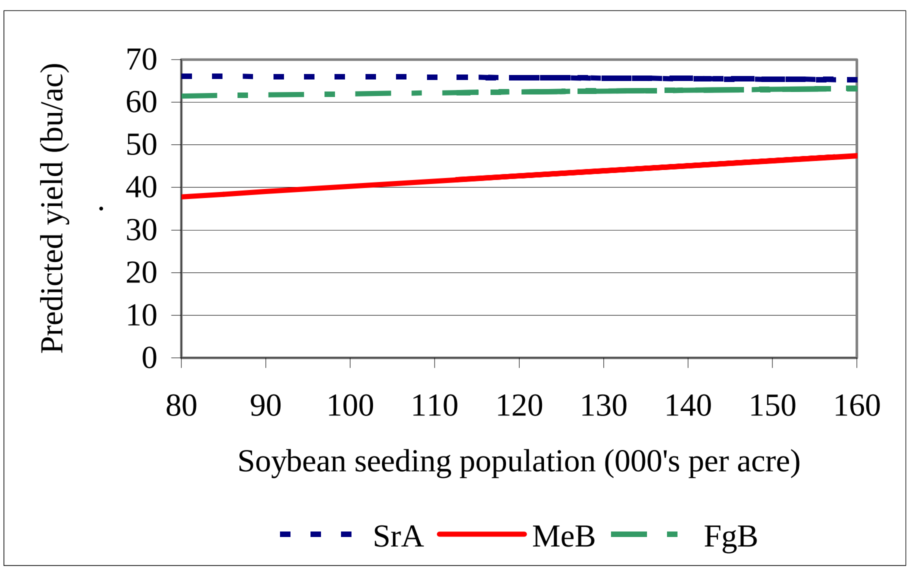


Figure 3. Predicted yield response to soybean seeding rate using traditional analysis

to 170K on Martinsville-Ockley (Table 4). It should be noted that the 170K seeding rate was higher than the highest seeding rate included in the experiment and may not have been properly estimated. The Fincastle-Miami soil had an agronomic optimal rate of

133K seeds per acre similar to Starks-Crosby. When the economic analyses were conducted, the whole field profit maximizating rate (economic) was 115K seeds per acre. The rates for Starks-Crosby and Fincastle-Miami were similar at 111 and 119K seeds per acre, respectively, however the Martinsville-Ockley rate was 156K seeds per acre. As previously stated, the highest seeding rate tested on Martinsville-Ockley may not have been high enough to adequately estimate yield response.

Table 4. Optimal agronomic and economic seeding rates

	Portion of field			
	Whole field	SrA	FgB	MeB
Optimal seeding rates (1000 seeds per acre)				
Agronomic	129	125	133	170
Economic*	115	111	119	156

*Soybean price of $5.50 per bushel and seed cost of $0.20 per 1,000 seeds
Soils as defined by USDA-NRCS

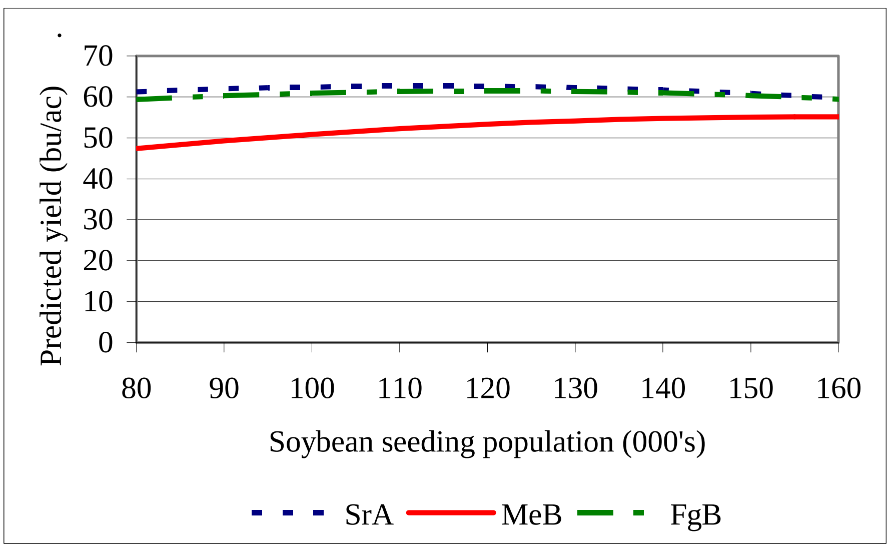


Figure 4. Predicted yield response to soybean seeding rate using spatial analysis

Impact of non-optimum seeding rates

Although the classical shape of the yield response curve was estimated, the yield response curve was relatively flat (Figures 4 and 5) indicating that non-optimum seeding rates may not adversely affect soybean yield and profitability. Tables 5 and 6 present the predicted effect on yield and economic returns when improper seeding rates were applied. These non-optimal seeding rates are the economic optimal seeding rates for the alternative soils. In most non-optimal seeding rate scenarios, measurable changes in predicted yield were not distinguished. It was only when Martinsville-Ockley rates were

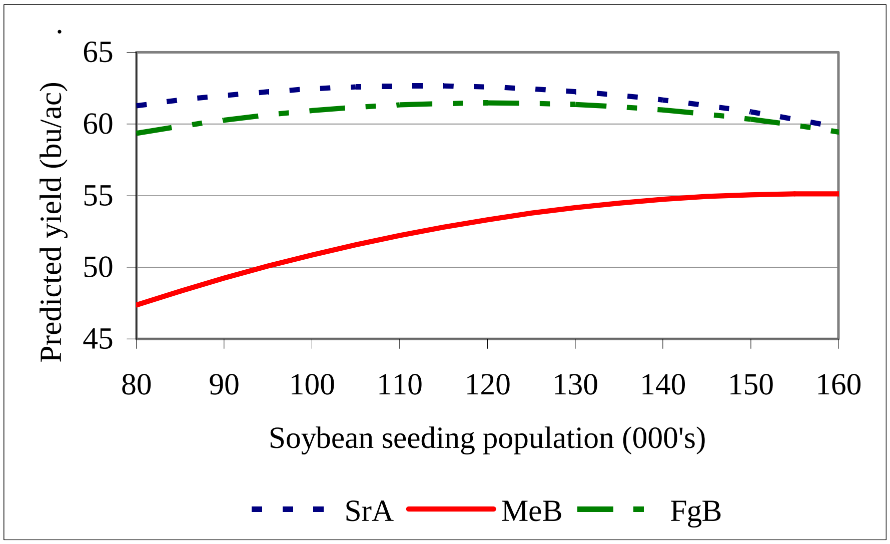


Figure 5. Detail of predicted yield response to soybean seeding rate using spatial analysis

Table 5. Change in predicted yield by alternative seeding rates

	Portion of field			
Rate (000 seeds per acre)*	Whole field	SrA	FgB	MeB
Whole field (115)	0.0	-0.1	0.2	3.7
SrA (111)	0.2	0.0	0.4	4.2
FgB2 (119)	-0.1	-0.2	0.0	3.1
MeB (156)	0.7	1.0	0.4	0.0

*Economic optimal seeding rates
Highlighted cells indicate appropriate rate at appropriate location

applied to the whole field, Starks-Crosby, or Fincastle-Miami and vice versa that substantial economic losses were detected. The Martinsville-Ockley soil was more sensitive to non-optimal economic seeding rates appropriate for other soils than the other soils receiving the seeding rate appropriate for Martinsville-Ockley (Table 5).

Table 6. Predicted returns by alternative seeding rates

	Portion of field			
Rate (000 seeds per acre)*	Whole field	SrA	FgB	MeB
Whole field (115)	339	342	336	288
SrA (111)	339	343	335	286
FgB2 (119)	339	342	336	291
MeB (156)	327	328	326	300

* Economic optimal seeding rates
Highlighted cells indicate appropriate rate at appropriate location

Sensitivity variable rate seeding to proportion of soils in field
Although soybean yields were not significantly different between Starks-Crosby and Fincastle-Miami soils, there was a statistically significant difference between yield response to seeding rates (Appendix A1). Since soybean yields responded similarly to seeding rates on the Starks-Crosby and Fincastle-Miami soil mapping units, Starks-Crosby and Fincastle-Miami soils were combined in Table 7 to determine what percentage of Martinsville-Ockley would induce the farm manager to use variable rate seeding under differing variable rate (VR) seeding costs. As low as 20% of the field in Martinsville-Ockley would entice the farm manager to perform VR seeding at the $2.42 per acre VR seeding cost reported in Akridge and Whipker (2005). However, the study field has 3.6% of the Martinsville-Ockley soil. Variable rate costs would have to be below $0.45 per acre before Martinsville-Ockley soil would receive a site-specific seeding rate. As the cost of variable rate seeding increased, the percentage of Martinsville-Ockley soil such that variable rates were feasible decreased. In the case of this study and Farmer "F", variable rate planting capability is already present on-site although other costs such as analysis and human capital should be accounted for.

Table 7. Breakeven proportion of Martinsville-Ockley soil in field

VR Seed cost $ per acre	Rest of field %	Martinsville-Ockley %
0.45*	96.4	3.6
2.00	83.8	16.2
2.42**	80.3	19.7
5.00	58.2	41.8
7.50	36.9	63.1
10.00	15.6	84.4

*Breakeven for study field with Martinsville-Ockley comprising nearly 4% of field area
**Average VR seeding charge per Akridge and Whipker (2005)

Summary

In general, soybean yields were highest on Starks-Crosby and lowest on Martinsville-Ockley soil. The Fincastle-Miami soil responded similarly to Starks-Crosby although minor differences were documented including a slightly higher but significantly different optimal seeding rate. Results of this study suggest that soybean seeding rates may be as low as 110 to 120K seeds per acre and still be maximizing profits. However, sensitivity tests suggest non-optimum seeding rates may not adversely affect yield however due to seed costs, profitability is affected.

Caution must be taken with respect to making decisions on Martinsville-Ockley soil for two reasons. First, it should be noted that Martinsville-Ockley soil may not have been a large enough portion of the Burkett field to have an adequate amount of yield observations. Second, higher seeding rates are necessary to properly estimate the yield response on Martinsville-Ockley soil and to make appropriate recommendations. Future research on a wider range of soils with sufficient observations per soil may provide information suitable for making variable rate application prescriptions. In addition, a precise delineation of soil units or 'management zones' based upon soil characteristics affecting yield response may allow higher precision in estimating yield response and making decisions. The depth of the topsoil would be useful in assisting with these recommendations, and may assist in delineation of 'management zones' due to potential erosion on hilltops and steep slopes, in particular with the Martinsville-Ockley soil. Without spatial analysis, evaluation of this site-specific dataset would not have produced usable results.

References

Conley, Shawn P. and Greg Shaner. 2006. Profitability of Cutting Seeding Rates: Fact or Fiction. Available on-line at: http://www.agry.purdue.edu/ext/coolbean/SPS_2006/Profitability.pdf

Drummond, S. 2006. Yield Editor 1.02 Beta Version. Available on-line at: http://www.ars.usda.gov/services/software/download.htm?softwareid=20

Griffin, T.W., Brown, J.P., and Lowenberg-DeBoer, J. 2005d. Yield Monitor Data Analysis: Data Acquisition, Management, and Analysis Protocol. Available on-line at: http://www.purdue.edu/ssmc

Illinois Agronomy Handbook available on-line at: http://iah.aces.uiuc.edu/

Whipker, L.D, and J.T. Akridge. 2005. 2005 Precision Agricultural Services Dealership Survey Results Staff Paper No. 05-11. www.purdue.edu/ssmc

Table 8: Spatial analysis regression output

VARIABLE	Coefficient	standard error	z-value	probability
Intercept	43.168	5.302	8.141	0.000
POP	0.292	0.067	4.335	0.000
POP_SQ	-0.001	0.000	-4.687	0.000
MeB	-23.197	4.802	-4.830	0.000
FgB2	-3.545	2.229	-1.591	0.112
POP_MeB	0.116	0.018	6.321	0.000
POP_FgB2	0.020	0.009	2.196	0.028
Elevation by MeB	0.342	0.188	1.818	0.069
Elevation by FgB2	-0.051	0.109	-0.473	0.637
Elevation	1.089	0.296	3.673	0.000
Elevation squared	-0.053	0.008	-6.828	0.000
POP by elevation	0.002	0.001	1.641	0.101
Relative elevation	0.957	0.156	6.134	0.000

* Evaluated at minimum elevation, i.e. minimum elevation equaled zero
N=3,897